Sensitivity Analysis of Seals Permeability and Performance Assessment of Deep Borehole Disposal of High-Level Radioactive Waste

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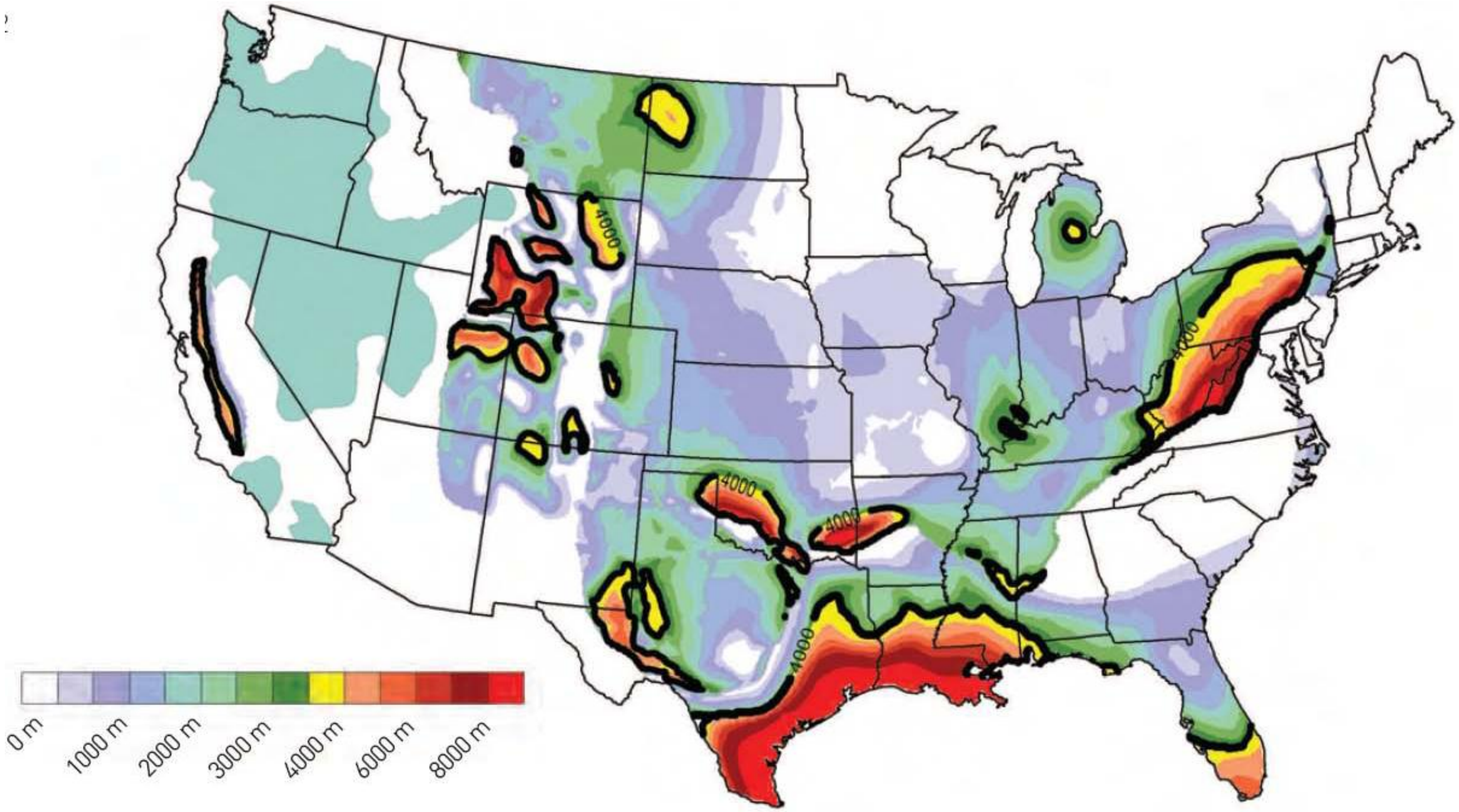
Potential of Deep Borehole Disposal of High Level Radioactive Waste

- Crystalline basement rocks are common in many stable continental regions
- Advances in drilling technology
- Low permeability and high salinity in deep crystalline basement suggests very limited interaction with shallow fresh groundwater resources
- Geochemically reducing conditions limit solubility and enhance the sorption of many radionuclides
- Density stratification of saline groundwater underlying fresh groundwater would reduce thermally induced groundwater convection

Depth to Crystalline Rock



Source: MIT 2006. *The Future of Geothermal Energy*

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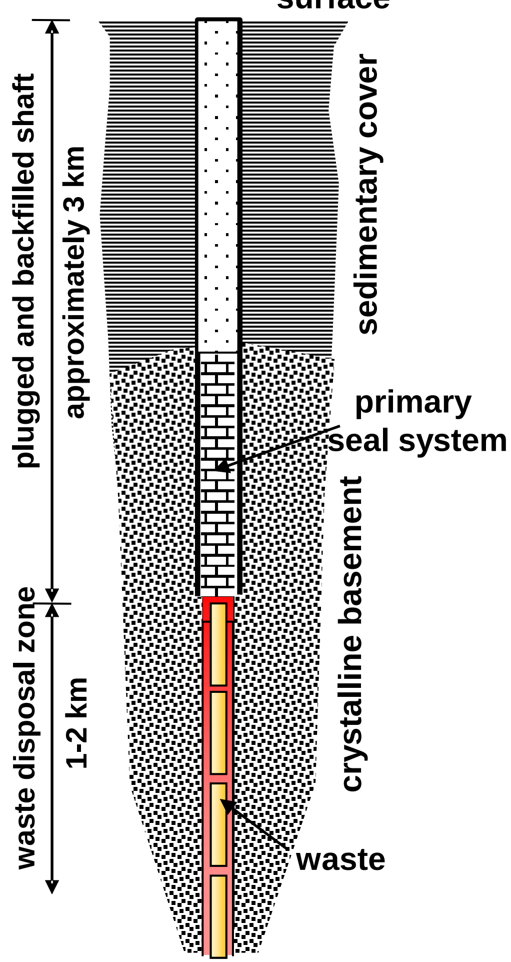
The Deep Borehole Disposal Concept

- Nominal 5 km borehole, with 45 cm bottom hole diameter
- For disposal of commercial nuclear fuel (UNF) waste borehole diameter can accommodate 1 PWR assembly
- Lower 3 km in crystalline basement
- 2 km waste emplacement zone
- 1 km of robust seal system



(not to scale)

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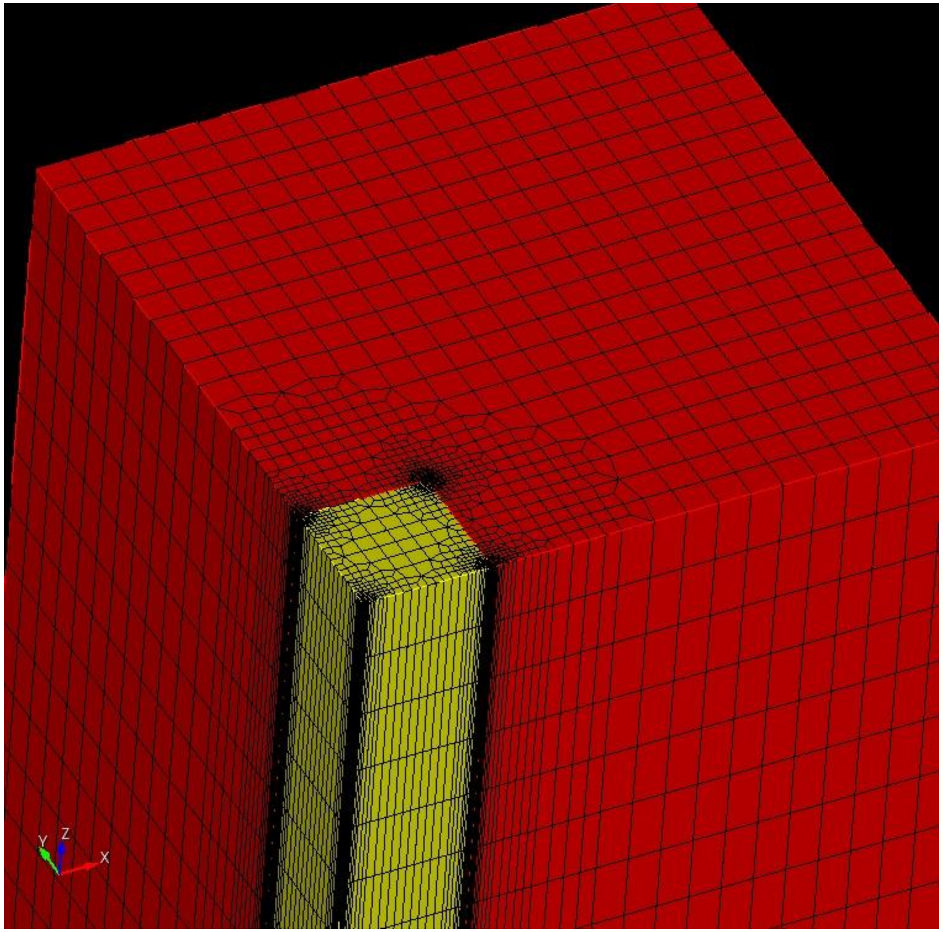
Numerical Simulation of Thermal-Hydrology



- Decaying heat from high level radioactive waste
- Modeled volume = 2 km x 2 km x 6 km
- Base Case: 9 boreholes and 200 m spacing
- Disturbed Rock Zone (DRZ) within a diameter of 1.13 m, and host rock beyond
- FEHM software code used

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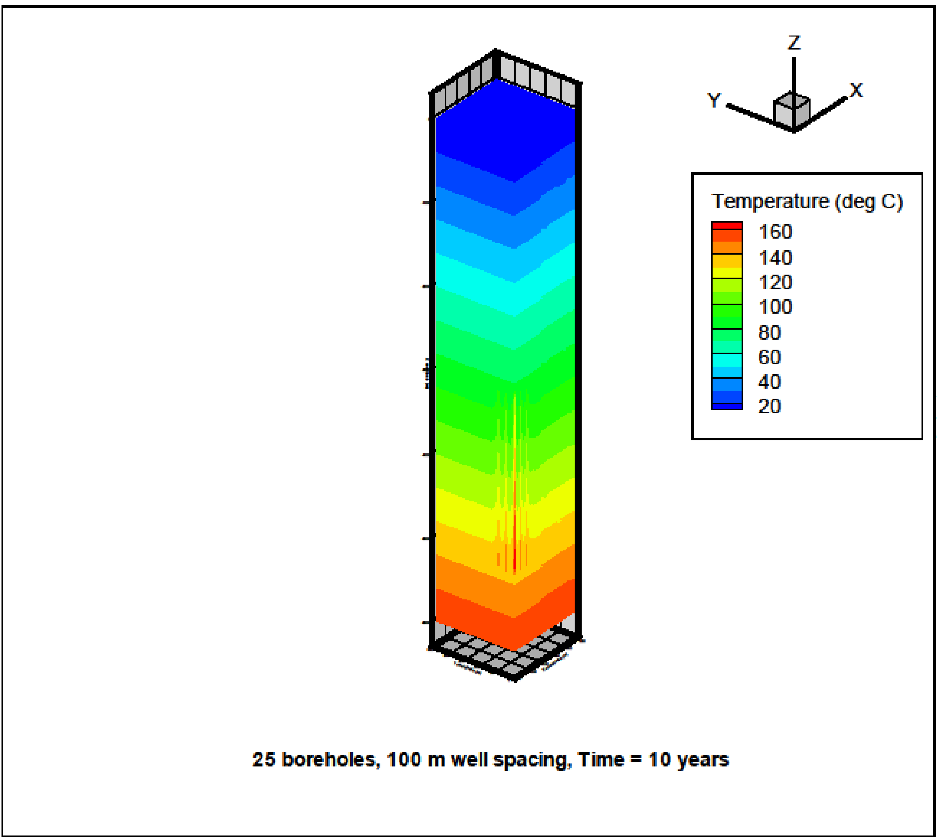
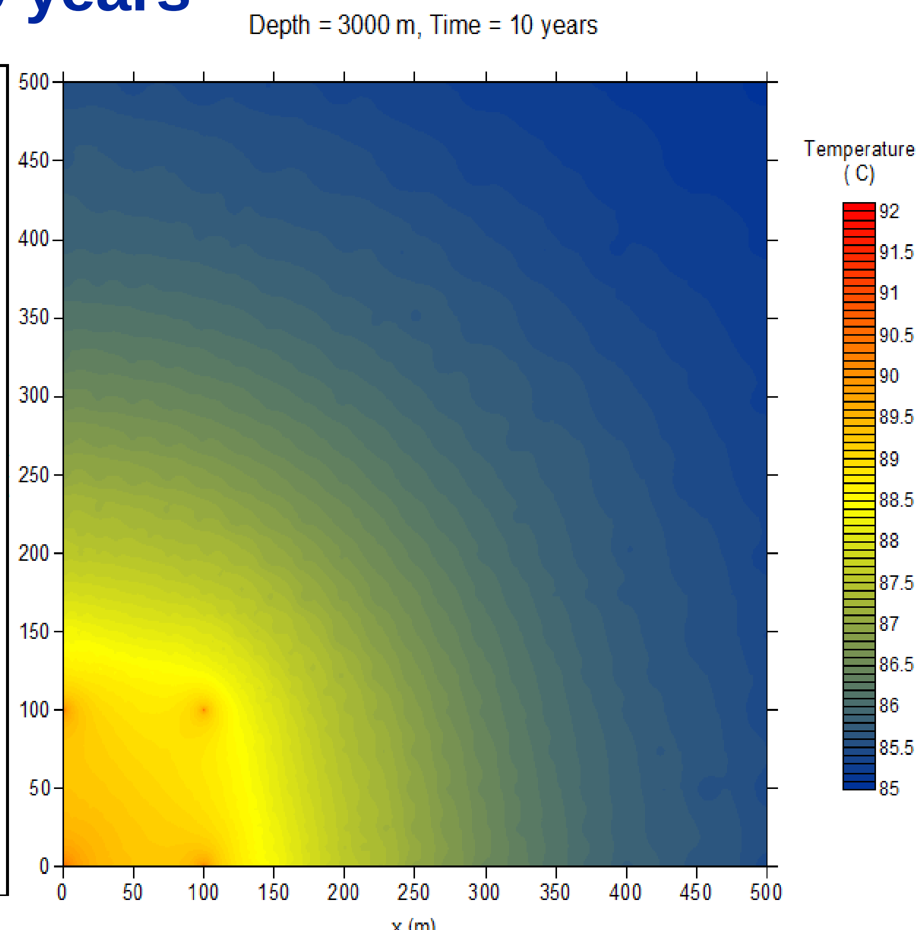
Thermal-Hydrology Simulation Results

Temperature distribution at 10 years





Heated fluid remains liquid

Rock and Disturbed Zone Permeability Values Used in Seals Study

Host rock Permeability (m^2)	10^{-19}	10^{-18}	10^{-17}	10^{-16}
	Disturbed Zone Permeability (m^2)			
	10^{-15}	10^{-14}	10^{-13}	10^{-12}
	10^{-16}	10^{-15}	10^{-14}	10^{-13}
	10^{-17}	10^{-16}	10^{-15}	10^{-14}
	10^{-18}	10^{-17}	10^{-16}	10^{-15}
	10^{-19}	10^{-18}	10^{-17}	10^{-16}

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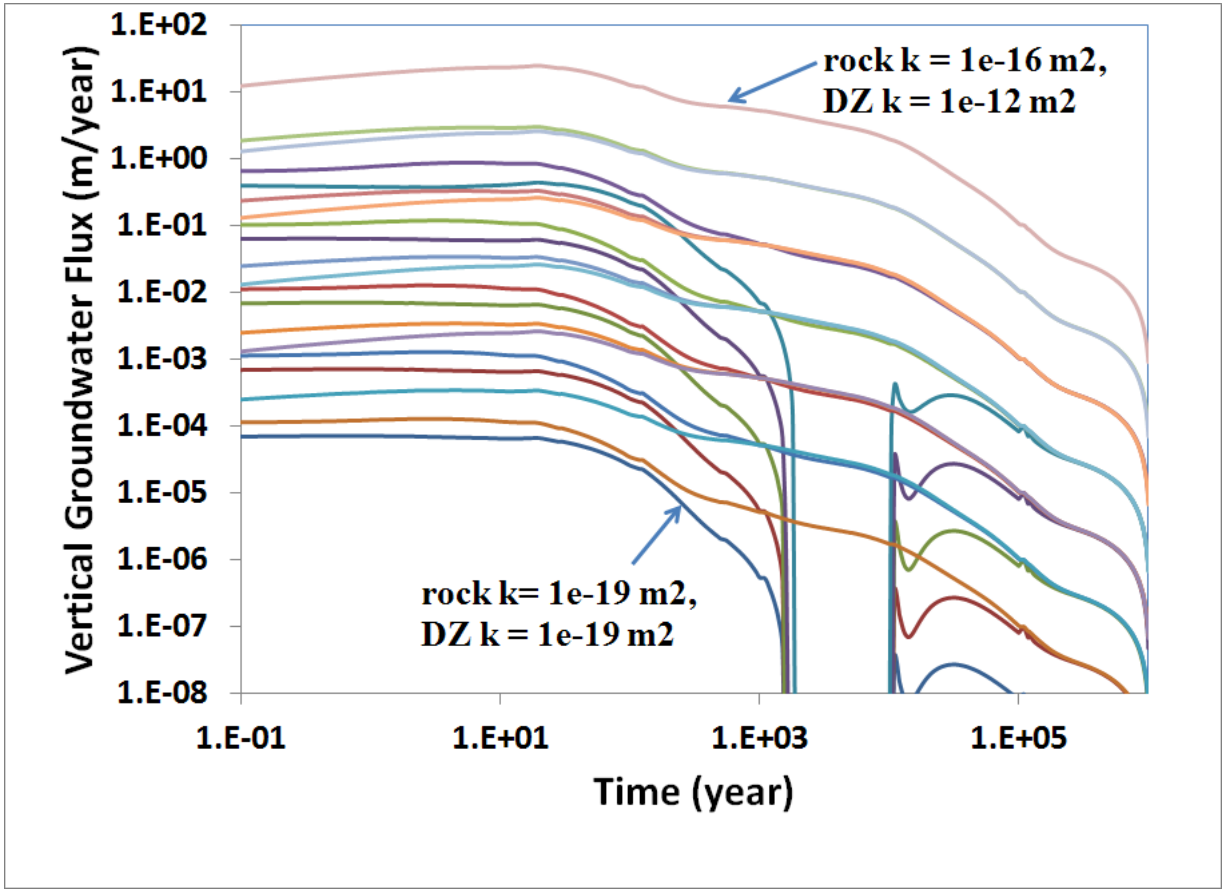
Seals Study Thermal-Hydrology Simulation Results (3000 m Depth)



- Vertical upwards flux highly dependent on permeability
- Some downward flux at low host rock permeability

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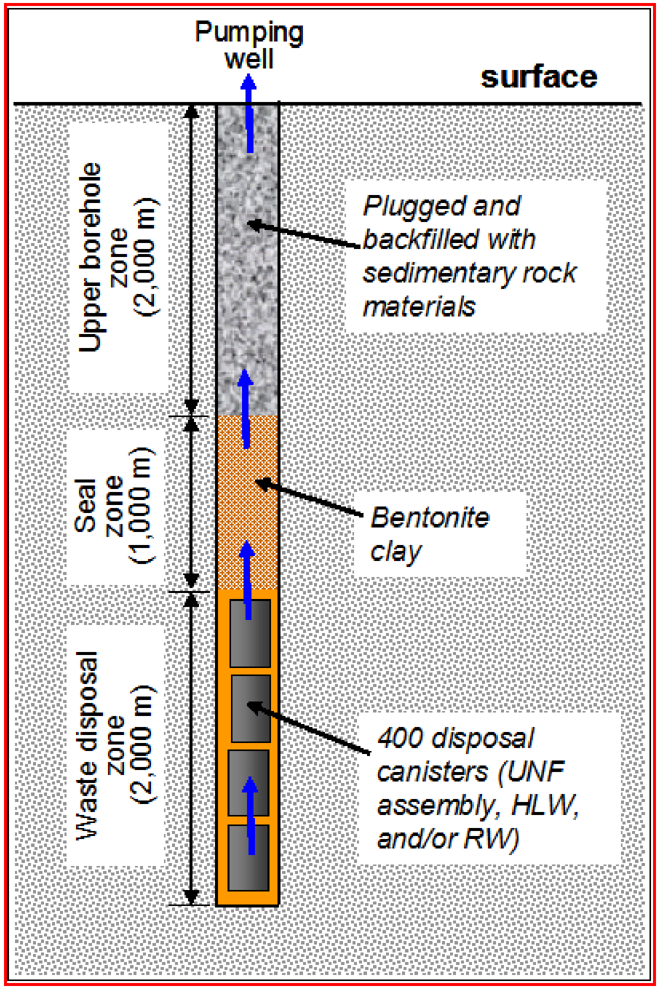
Performance Assessment Conceptual Model for a Single Disposal Borehole

- Model domain consists of three zones
- Time varying vertical groundwater flow from thermal-hydrology simulations applied in waste disposal and seal zones
- Constant groundwater flow driven by 3-D radial flow to a water supply well applied in the upper-borehole zone
- Flow and radionuclide transport in waste-disposal and seal zones occurs in 1 m^2 cross-sectional area



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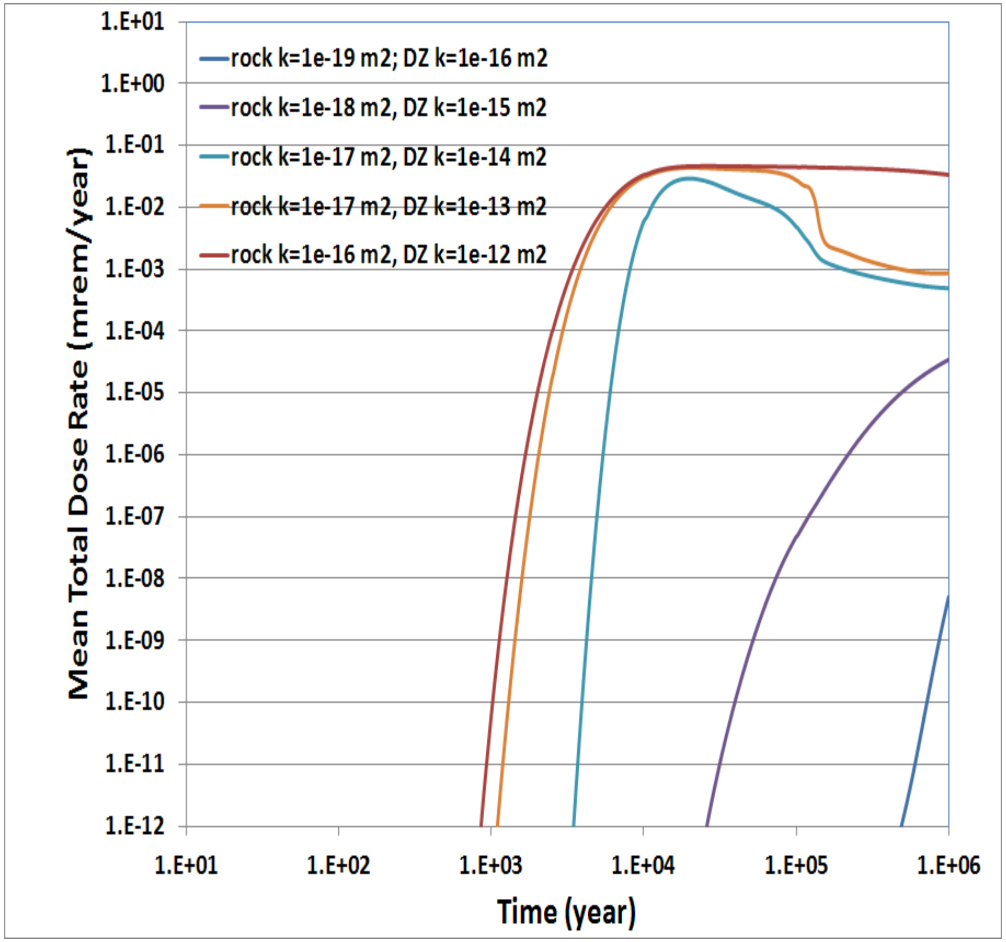
Performance Assessment Conceptual Model(Contd.)

- Model includes transport processes of advection, dispersion, diffusion, sorption, decay and ingrowth.
- Probability distributions for fractional waste-form degradation rate, radionuclide solubility limits, and sorption coefficients were used to describe uncertainty.
- Releases to biosphere diluted in 10^4 m^3/year water supply
- Monte Carlo simulations with 100 realizations for a period of 10^6 years. Latin Hypercube sampling used.
- Disruptive events and borehole intrusion not considered
- Outputs include releases and annual radiation doses
- Numerical model implemented using GoldSim code

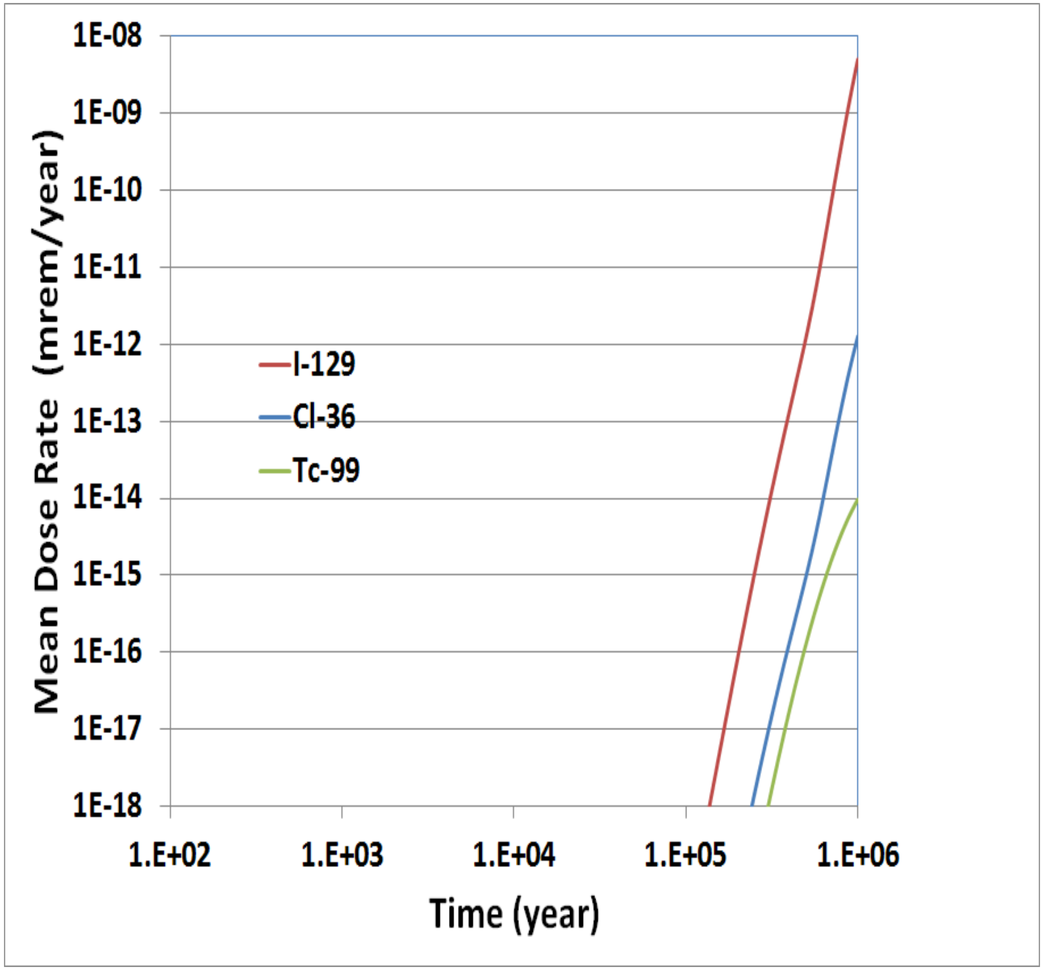
Performance Assessment Preliminary Model Results: Mean Annual Total Dose Rate

- Disposal of commercial nuclear fuel (UNF) modeled
  - 400 disposal canisters
  - Inventory assumed to be uniformly distributed over the length of disposal zone
- Results shown for a single disposal borehole for five selected permeability cases
- For base case permeability values estimated doses are negligibly small
- For bounding high permeability values estimated doses are low



Performance Assessment Preliminary Model Results: Radionuclide Contributions to Dose

- Dose contributions of radionuclides for the base case permeability values shown
- I-129 is the dominant radionuclide. Cl-36 and Tc-99 are minor contributors
- The non-sorbing radionuclides of I-129 and Cl-36, and the mildly sorbing radionuclide of Tc-99 account for most of the dose



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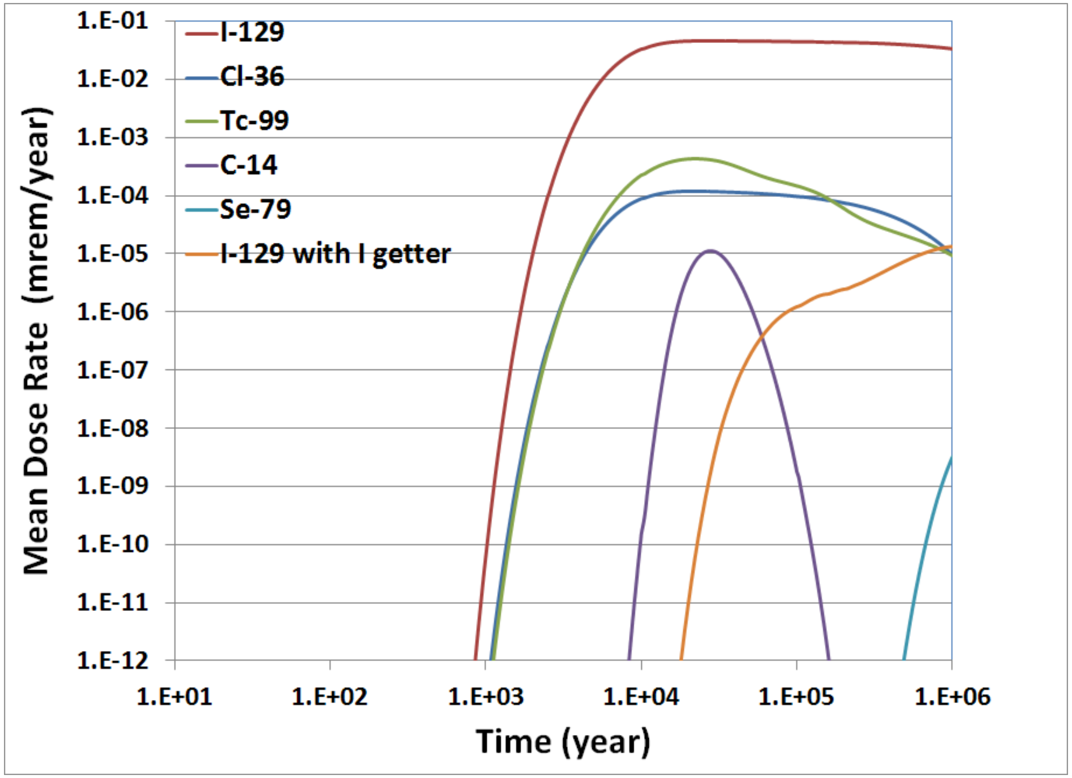
Performance Assessment Preliminary Model Results: Use of Iodine Getter

- **The base case assumed unlimited solubility, no sorption and very long half-life of I-129.**
- **Sorption of I-129 by getters (sorbents) in seals considered**
- **For the upper bound permeability values use of I-129 getter significantly reduces the peak dose.**



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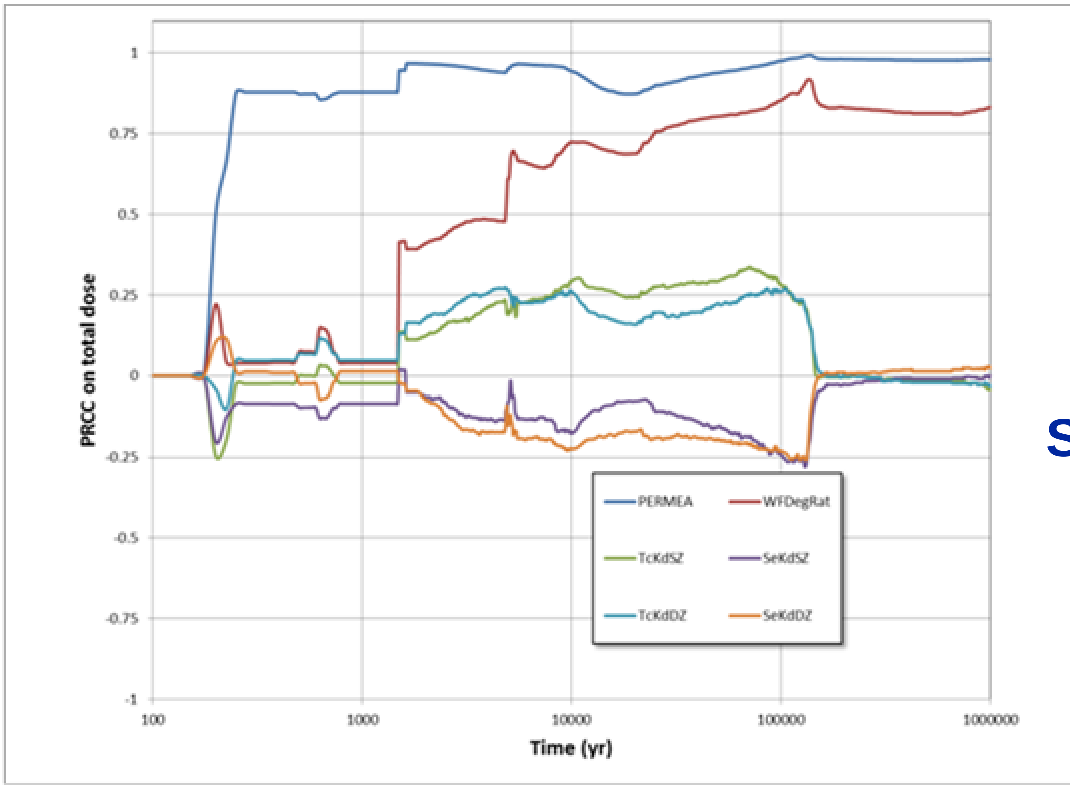
Sensitivity Analysis

- Sensitivity analysis is an integral part of system performance assessment
- The purpose of the sensitivity analysis is to identify the most important parameters that affect uncertainty in dose
- The relative importance of a parameter is a function of the inherent sensitivity of the model and the amount of uncertainty in that parameter
- The analysis was performed by computing Partial Rank Correlation Coefficients (PRCCs) and Stepwise Rank Regression Coefficients (SRRCs)

Case 1: With no Iodine Sorption and with Permeability as an Uncertain Parameter

- Permeability was not part of the original 100 LHS samples. To include permeability in the sensitivity analysis, permeability indicator function PERMEA was introduced to represent the selected five permeability runs (PERMEA: 1 to 5)
- LHS approach was used to generate values from a discrete uniform distribution {1;2;3;4;5}
- Based on the assumption that the runs with different permeability values were equally probable, PERMEA was the most important parameter of the sensitivity analysis, followed by fractional waste form degradation rate (WFDegRat)

Case 1 – Sensitivity Analysis Results



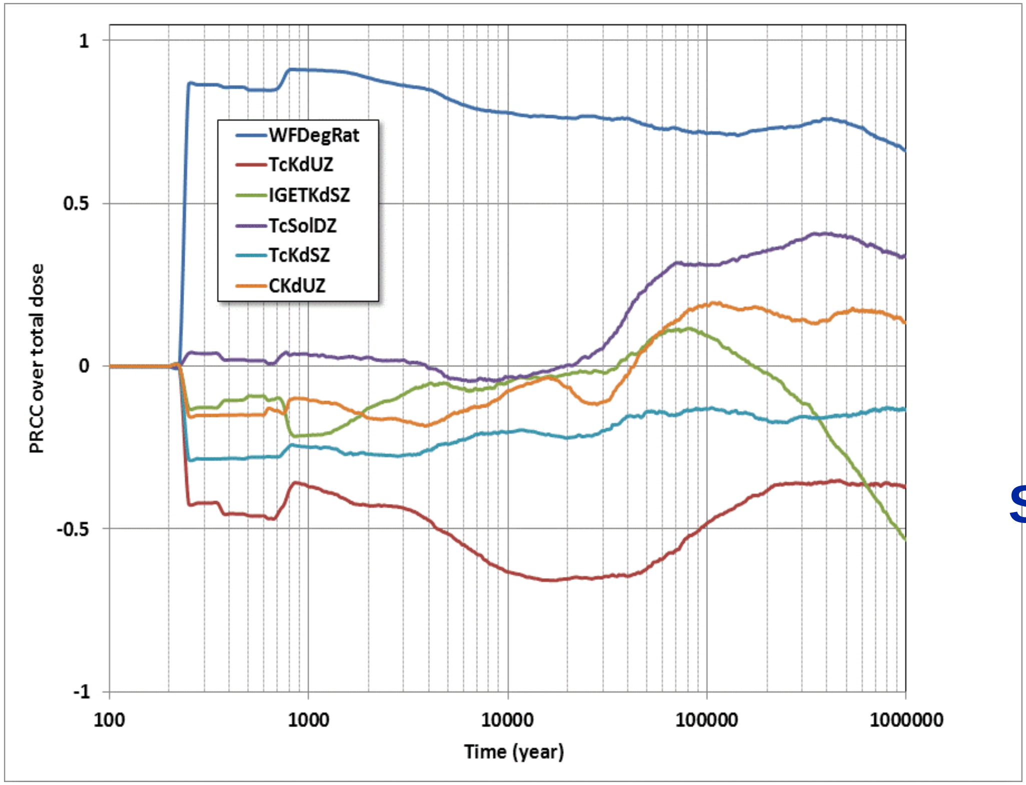
Var. Name	R^2	R^2 contribution	SRRC
PERMEA	0.878	0.878	0.966
WFDegRat	0.961	0.084	0.291

Stepwise regression at 10^6 years

PRCCs for Total Dose over time

Case 2 – With Iodine Sorption and Without Permeability as an Uncertain Parameter

- To study influence of other parameters (Rock $k=10^{-16}\ m^2$, DZ $k=10^{-12}\ m^2$)
- The use of Iodine getter reduces the contribution of I-129 to total dose which highlights the contribution of Tc-99



PRCCs for Total Dose over time

Var. Name	R^2	R^2 contribution	SRRC
WFDegRat	0.301	0.301	0.562
IGETKdSZ	0.457	0.155	-0.415
TcKdUZ	0.528	0.071	-0.270
TcSolDZ	0.582	0.054	0.238

Stepwise regression at 10^6 years

Conclusions

- 3-D thermal hydrology model was used to provide thermally driven vertical groundwater fluxes as input to PA modeling
- A PA model was developed to evaluate aspects of the long-term performance of deep borehole disposal
- Preliminary simulation results support the conclusion that deep borehole disposal is a potential option for high-level waste disposition
- Sensitivity analysis showed that assuming that each of the selected permeability varying cases are equally probable, permeability has the highest effect on total uncertainty, followed by waste form fractional degradation rate. This is because the transport of the dominant radionuclide, I-129, is affected by these parameters.
- When Iodine getter is used to cause sorption of Iodine, other parameters such as sorption and solubility of Technetium increased contribution to total uncertainty